OKLAHOMA GEOLOGICAL SURVEY
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FRANK BUTTRAM.

NORMAN
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SCIENTIFIC STAFF.

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CONTENTS

CHAPTER III.—VOLCANIC DUST IN OKLAHOMA.

ILLUSTRATIONS.

VOLCANIC DUST IN OKLAHOMA.

INTRODUCTION.

The presence of volcanic dust in Oklahoma has been known for some years, but inasmuch as there is at present no definite information concerning this material, the Oklahoma Geological Survey assigned to the writer the duty of making a somewhat detailed search in the State for any existing deposits of volcanic dust and publishing the results of this investigation as a Survey bulletin.

The field work for this report was carried on during the spring of 1913. During the prosecution of this work it was discovered that volcanic dust exists in greater or less quantities over a large portion of the State and it is altogether probable that some dust is disseminated in the surface soil over the entire State. In several different localities large deposits of the dust were found. The limited time spent in the field did not permit of a detailed study of these deposits and although there was a general investigation over the entire State, yet there may be some deposits of considerable magnitude that were not discovered. Since the field work was completed numerous samples of volcanic dust from scattered localities over the State have been sent in by individuals. These occurrences are included in the report.

It is the writer's purpose in this report to give a general discussion on the volcanic dust deposits which were found in several different counties of the State; to discuss the origin and probable source of the dust in these deposits; and also to discuss the means of its transportation, physical and chemical characteristics, and economic value. In order to treat these phases of the subject intelligently and to give the reader a general idea of volcanic phenomena, it has been found advisable to divide the report into three general chapters. The first chapter discusses briefly the different types of volcanoes, their distribution and origin; the second chapter deals with the origin, distribution, physical and chemical properties, and economic value of volcanic dust; while the third chapter discusses the occurrence of volcanic dust in Oklahoma.

CHAPTER 1.

TYPES OF VOLCANOES.

In the discussion below concerning general volcanic phenomena, the writer does not claim any originality, his purpose being merely to give a brief summary of existing knowledge. It is hoped that these data will enable the reader to grasp a somewhat broader idea of the earth and its interior as well as its exterior.

There are three types of volcanoes, namely, the quiet, intermediate, and explosive types.

Quiet Type.

In some volcanoes lava, magma, or melted rock lies quietly in the crater, or sometimes flows gently through breaches in the rim of the crater, or again, may well up through fissures on the slope of the volcano.

The Kilauea volcano in the Hawaiian Islands is an example of this type. It occurs near the northeast coast of the Island of Hawaii, which is the largest and easternmost island of the Hawaiian group. The highest point of the crater is only 4,158 feet above sea level, and the crater is almost 7 1-2 miles in circumference. In most places the interior walls are almost vertical and have a height of about 900 feet, as is the case with the crater of Popocatapetl in Mexico (Pl. I.)

Although at present Kilauea is an excellent example of the quiet type of volcanoes yet it has had several violent eruptions, and it may be said with a considerable degree of certainty that the craters of all great volcanoes have their beginnings in a great discharging fissure, or in the crossing of two such fissures. It is known by experiment and otherwise that basalt and other similar rocks melt at a lower temperature than granite and related rocks. Hence, the phenomena of Kilauea are considered as largely due to the fact that it is a basalt volcano in its normal state and the heat is sufficient to produce a high degree of mobility in the lavas, and to give full and free action. The obvious results of this free mobility in the lavas are threefold:

First. The lavas have a greater velocity on like slopes and are less likely to be impeded by obstructions, and consequently the lava cones have a smaller angle of slope than is the case with granite lavas.

Pl. I. The vertical walls of the immense crater of Popocatapetl.
(Courtesy National Geographic Magazine.)

Second. The vapors ascending through the liquid lava encounter comparatively feeble resistance, therefore, the expansive force required for escape of bubbles through the lava to the surface is feeble and hence in case of explosion projected masses usually go only to a small height.

Third. The large, quiet upwelling of lava from volcanoes of this type rarely alternates with explosions which produce cinder or tufa deposits.

Intermediate Type.

Vesuvius is a good example of the intermediate type. The steep, conical summit in the Bay of Naples rises to a height of 400 feet within a truncated and half-destroyed crater of an older and much larger volcano. From the earliest historic times until 79 A. D., the volcano was dormant and its crater cold and overgrown with vegetation. In the year mentioned, however, a violent explosion occurred which blew away a large part of the ancient crater and buried the historical towns of Pompeii and Herculaneum beneath the lava and fragmental products that were ejected. Since then Vesuvius has been dormant for many years at a time, but there has always followed a period of renewed activity and in some instances explosions have become sufficiently violent to hurl stone and dust high in the air, distributing them far and wide over the adjacent region and even causing southern Italy to be shaken by earthquakes. These alternating periods of activity and inactivity have been designated as the Vesuvian stage, while in volcanoes where the mild activity is continuous as in the case of Stromboli, they are classified as the Strombolian stage.

The following description* gives a good word picture of Vesuvius as it appears during mild activity:

In November, 1879, I climbed the cone composed of loose fragments of lava, forming the summit portion of Vesuvius, and reached the rim of the bowl-shaped depression at the summit. The crater near the summit then had an outer slope of about 35°; the inner slope was more precipitous, and exposed the edges of the outward-dipping layers of fragmental material, showing that the opening had not long previously been enlarged by the blowing away of the inner portion of its rim. This occurred perhaps during the energetic eruption of 1872. The crater was by eye measurement 150 to 200 feet deep, and a thousand feet in diameter. It was floored with black, slag-like lava. The lava in many places was wrinkled or corrugated, owing to slow movement before cooling, and intersected by numerous fissures through which the glowing, red-hot rocks beneath could be plainly seen. From some of the fissures, steam was escaping with a hissing noise. In the central portion of the floor of hardened lava, and resting on it, was a rough, conical pile of

slag-like lava, rising to a height nearly as great as the highest portion on the encircling rim. This inner pile was the *cone of eruption.* From its summit great volumes of vapor were rolling out, accompanied by puffs which sent globular masses of steam high in the air. With each puff, stones four or five inches in diameter and highly heated, were hurled to a height of between one and two hundred feet in the air. Some of the stones fell on the sides of the conical pile, and occasionally one would roll to its base. At each explosion the entire crater vibrated, but not sufficiently to be at all alarming.

Explosive Type.

This type of volcano is the principal source of volcanic dust and therefore is of first order of importance in this report. Mount Katmai, Mount Pelee, and Krakatoa are excellent examples of this type, and since this type produces most of the volcanic dust, a more extended account of these volcanoes will be given.

Mount Katmai, a volcanic peak of 7,500 feet height, is located near the eastern end of the Alaskan peninsula. For ages this peak was dormant, but on the 6th of June, 1912* without any fore-warning, the previously dormant volcano proclaimed itself by violent eruption, and the sound of the first mighty explosion carried down the coast as far as Junau, 750 miles away, and was even heard across the Alaska Rouge at Dawson and Fairbanks, distant 650 and 500 miles respectively. Midnight blackness in the day time extended as far east as Kenai peninsula. Darkness lasted sixty hours at Kodiak, 100 miles from the volcano. The dust approached this island in the form of a vast cloud. On some parts of the island the deposit of dust was as much as 10 inches (Pl. II).

A further idea of the enormous quantity of dust may be gathered from Plates III and IV. A general idea of the amount of ash falling in the general vicinity of the volcano may be had from Plate V, which shows the region affected by the Katmai eruption and the fall of ash at various distances. The thickness of ash is shown by curves of approximately equal depth, and by figures showing measured depth in inches. At first thought this may appear to be a tremendous explosion, yet when compared with some former explosions, it is mediocre both in intensity and amount of material ejected.

Students of volcanicity are more or less familiar with Mount Pelee, situated on the Island of Martinique at the eastern end of Carribean Sea. Mount Pelee has had three periods of activity within historic times: namely, in 1762, 1851, and 1902. From 1851 to 1902 the volcano slumbered. For two weeks previous to May 8, 1902, when the activity of the volcano reached its climax, there were

*Martin, Geo. C., National Geographic Magazine, Feb. 1913.

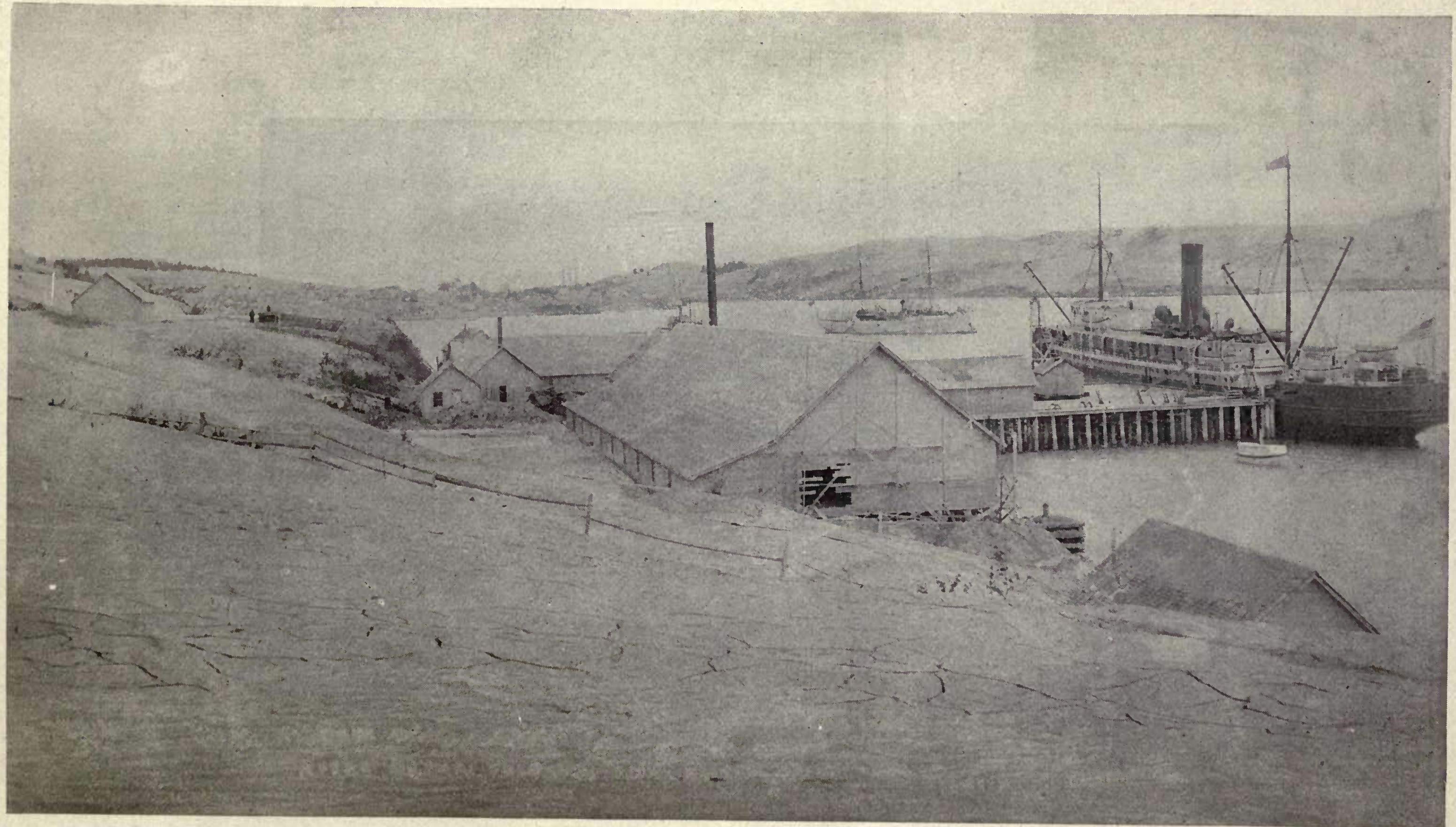


Plate II. Kodiak fisheries covered with 10 inches of ash from Katmai volcano which is 100 miles away.
(Courtesy National Geographic Magazine.)

Plate III. The end of the fall of dust at Kodiak.
(Courtesy National Geographic Magazine.)

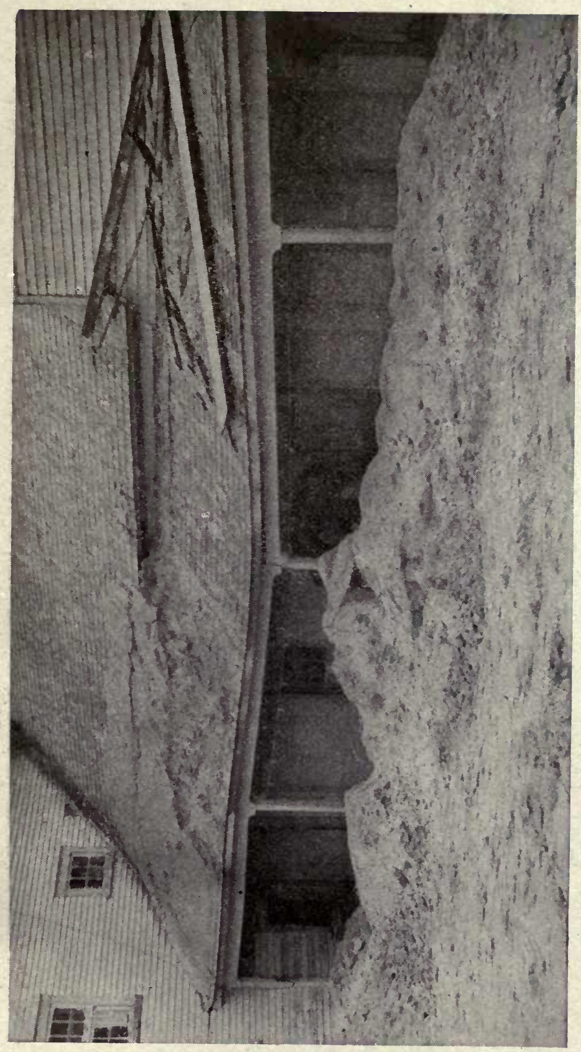
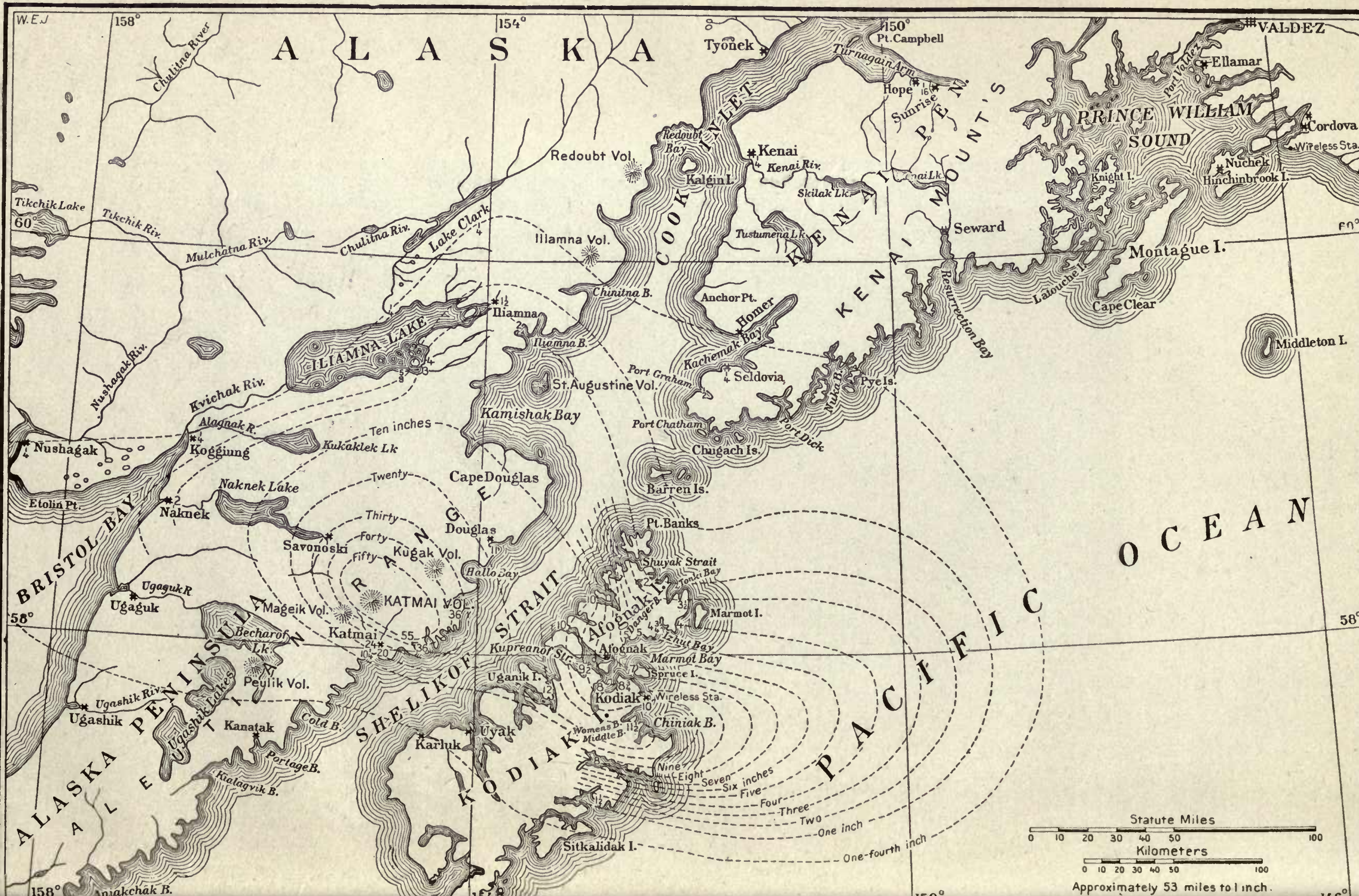


Plate IV. A porch which collapsed beneath the weight of ashes at Kodiak.
(Courtesy National Geographic Magazine.)



ALASKA
W.E.J
158°
154°
150°
146°
60°
58°
Chulitna River
Tikchik Lake
Tikchik Riv.
Mulchatna Riv.
Chulitna Riv.
Lake Clark
Redoubt Vol.
Iliamna Vol.
Iliamna
ILIAMNA LAKE
Nushagak Riv.
Kvichak Riv.
Alagnak R.
Koggiung
Nushagak
Kukaklek Lk
Ten inches
Twenty
Thirty
Forty
Fifty
Etolin Pt.
Naknek Lake
Naknek
BRISTOL BAY
Savonoski
Kugak Vol.
KATMAI VOL.
Mageik Vol.
Katmai
Ugaguk R
Ugaguk
Becharof Lk.
Peulik Vol.
Ugashik Riv.
Ugashik
Ugashik Lakes
Kanatak
ALASKA PENINSULA
ALEUTIAN RANGE
Cold B.
Portage B.
Kialagvik B.
Aniakchak B.
Tyonek
COOK INLET
Redoubt Bay
Kalgin I.
Chinitna B.
Iliamna B.
St. Augustine Vol.
Kamishak Bay
Cape Douglas
Douglas
Hallo Bay
SHELIKOF STRAIT
Kenai
Kenai Riv.
Skilak Lk.
Tustumena Lk.
Anchor Pt.
Homer
Kachemak Bay
Seldovia
Port Graham
Port Chatham
Chugach Is.
Port Dick
Nuka B.
Pye Is.
Barren Is.
Pt. Banks
Shuyak Strait
Tonki Bay
Afognak I.
Danger B.
Izhut Bay
Marmot I.
Afognak
Marmot Bay
Kupreanof Str.
Spruce I.
Uganik I.
Kodiak
Wireless Sta.
Chiniak B.
Womens B.
Middle B.
Uyak
Karluk
KODIAK I.
Sitkalidak I.
Nine
Eight
Seven
Six inches
Five
Four
Three
Two
One inch
One-fourth inch
PACIFIC OCEAN
Pt. Campbell
Turnagain Arm
Hope
Sunrise
KENAI PEN.
KENAI MOUNT'S
Seward
Resurrection Bay
Latouche I.
Montague I.
Cape Clear
PRINCE WILLIAM SOUND
Knight I.
VALDEZ
Port Valdez
Ellamar
Cordova
Wireless Sta.
Nuchek
Hinchinbrook I.
Middleton I.
Statute Miles
0 10 20 30 40 50 100
Kilometers
0 10 20 30 40 50 100
Approximately 53 miles to 1 inch.

discharges of steam, vapors, and dust, some of which were thrown more than 1,300 feet above the top of the mountain. On the 8th, within two minutes after the first great explosion had occurred, a heavy, black cloud of highly heated gases, steam, dust, and volcanic debris of all kinds had swept down the sides of the mountain to the city of St. Pierre, a distance of 5 miles. Buildings were wrecked, statues hurled from their pedestals, trees torn up, and in a few moments, almost the entire city with a population of 30,000 was completely destroyed.* Russell estimated that during each hour that Mount Pelee was in full blast something like 48,000,000,000 cubic

*Ann. Rept. Smithsonian Institute, 1902, p. 337.

feet of dust and stone-laden steam were driven out. The solid matter discharged was almost entirely in the condition of angular fragments varying in size from those weighing approximately 1,000 tons to the finest of dust particles.

Enormous as may appear the quantity of solid matter ejected from the volcano, which was in active eruption almost daily for over two years, it was but an insignificant fraction of the total substance emitted. Only a rough estimate can be made of the tremendous quantities of material that were ejected from the volcano in the shape of vapors and invisible gases. Some authorities have estimated the proportions of vapors and gases to solids to be in the ratio of 999 parts of the former to 1 of the latter.

It might be of interest to note that some thoughtful investigators are of the opinion that the waters in the great ocean basins have been made by contributions from the condensation of volcanic vapors which have been ejected from the numerous active volcanoes in past ages.

Probably the most violent and destructive explosion of which there is historical record was that of the Krakatoa in 1883, on an island in the Straight of Sunda, between Sumatra and Java.

Previous to the memorable explosions which occurred from August 26th to 28th and the preceding minor explosions, Krakatoa was dormant and overgrown with vegetation. The force of the explosion within the crater was sufficient to blow away about two-thirds of the island and the sea is now approximately 1,000 feet deep where the center of the volcano, 1,400 feet high, formerly stood. Enormous quantities of dust and steam were shot up into the air 17 to 23 miles and the sky over the island and the bordering coasts became black as night. Judging from the effects of the coloring upon sunsets it has been estimated that this dust traveled around the earth in 15 days. It has also been estimated that a part of the dust remained in the air at least three years after the ex-

plosion, and it is very probable that small amounts of this dust have found their way to nearly all parts of the earth.

Barometric observations taken in various parts of the world show that the great air-waves produced by the explosions traveled around the earth three and a half times. The time required for each complete circuit of the earth was about 36 hours and 30 minutes. The sound waves produced by the terrific explosion traveled great distances and were heard at Alice Springs in southern Australia, 2,233 miles; at Dutch Bay, Ceylon, 2,058 miles; and Chagoz Islands, 2,267 miles away. At Singapore, 522 miles away, two steamers were dispatched to look for the vessel in distress which was supposed to be firing signal guns. It is believed that the noise was heard over an area of one-thirteenth of the entire surface of the globe.

Great destruction was caused by the enormous sea-waves which formed as a result of the explosions and traveled half-way round the earth. The largest of these sea-waves on reaching the shores of Java and Sumatra rose to a height of 50 feet above the normal water level, and a Dutch warship was carried about 2 miles inland and left 30 feet above sea level. More than 30,000 perished and 295 villages were wholly or partially destroyed.

Notwithstanding the fact that the most prominent effect of volcanic eruptions like the ones referred to above is the destruction of property and life, yet they are beneficial in many ways. They have preserved records of the historic past by covering up ancient cities which have remained intact until the present time; they have also covered up many fossils and in this way have preserved a record of the geologic past. In addition to this, these eruptions have caused the formation of useful lakes and large areas of fertile soil, have aided in the making of beautiful scenery, and have assisted in the formation of valuable mineral deposits.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION OF VOLCANOES.

In general, volcanic vents occur near the shores of the ocean. They are often situated on islands, but are seldom at any great distance from the coasts of continents. The principal system of volcanic vents surrounds the Pacific Ocean and is sometimes termed the "chain of fire." The length of this vast system is about 30,000 miles. The Atlantic Ocean and its tributaries are also bordered by many volcanoes. There are at present about 300 active and several thousand dormant volcanoes. Only about one-third of the active

volcanoes are situated on continents, while the remainder occur upon islands scattered over the various bodies of waters.

Students of volcanicity who have made a study of the volcanic rocks over the different parts of the earth's crust are of the opinion that there has been volcanic activity from the earliest geological periods of the earth's history. The scene of volcanic action, according to all indications, has been continually shifting. In each area the volcanic activity gradually increased in intensity to a maximum, and then as slowly declined, but as it died away in one part of the earth's surface there was a period of activity that gradually made its appearance in another part. There are some authorities who believe that the subterranean energy is approximately a constant quantity with only local variations, while others believe that volcanic activity has varied considerably in the different geological periods. At present, however, there are not enough data to warrant any definite conclusions.

NATURE AND ORIGIN OF VOLCANIC ERUPTION.

Volcanic phenomena are the outward manifestations of forces beneath the crust of the earth and are produced by the escape of imprisoned steam and gases from masses of incandescent and possibly molten rock. The universality of these phenomena over the surface of the earth in present or past times, although they may vary much in intensity, indicates the existence of a general cause beneath the crust of the earth, even if large areas are to be found from which volcanic rocks are absent.

In order to account for volcanic phenomena it will be necessary to form as nearly as possible some definite idea not only of the condition of the interior of the earth but of the origin of the earth itself. Authorities do not yet possess conclusive information, but three hypotheses—the Laplacian, Meteoritic, and Planetesimal—have been advanced to account for the origin of the earth and to explain the condition of its interior, but none of these has proved entirely satisfactory.

Hypotheses on the Origin of the Earth.

It is not the purpose of this report to enter into a full discussion of the different hypotheses, and therefore only a brief summary will be given without any attempt to analyze the profound problems connected with each hypothesis pertaining to the origin of the earth.

LAPLACIAN HYPOTHESIS.

In the year 1796 Laplace in his publication on the Systemes du Monde laid down the principles of his nebular hypothesis, which, during the last century and up until the last few years, with a very few exceptions, has been universally accepted by men of science. The fundamental tenets of this hypothesis are as follows: (1) It assumes that the matter of the solar system which is now gathered into the sun and its planets was once in a highly heated gaseous condition in the form of a nebula extending beyond the outermost planet and rotating in the same direction as the present solar system. (2) Under the action of its own gravitation the nebula assumed a form approximately globular, having a rotary motion, the angular velocity of which increased as the sphere contracted as a result of the gradual loss of heat by radiation. (3) In consequence of the rotation the globe necessarily became flattened at the poles and ultimately, as the contraction went on, the centrifugal force at the equator became equal to the force of gravity and rings of nebulous matter became detached (not thrown off) from the central mass. The rings around Saturn suggested this feature of the hypothesis. (4) The ring thus formed for a time revolved as a whole, but eventually broke and the material collected into a single globe revolving around the central nebula as a planet. The matter of the ruptured ring rotated in the same direction as the ring had revolved. (5) The planet thus formed might leave behind rings of its own and so form for itself a system of satellites, which in turn continued to cool and contract.

METEORIC HYPOTHESIS.

According to this, the parent nebula is assumed to have been composed of meteorites sparsely aggregated into swarms with the members of each swarm moving in diverse directions and frequently colliding. Lockyer believes that the light of the nebulae is due to a collision of the meteorites, and the gaseous spectra given forth by some meteorites are due to the impact of the meteorites which vaporizes a part of them and the continuous spectra which still others present are due also to the solid or liquid portions being set aglow by collision. George H. Darwin came to the conclusion after an extensive study of the question, that a swarm of meteorites is dynamically analogous to a gas, and that the laws governing gases apply to its mechanical properties. Neither Lockyer nor Darwin attempts to trace completely the course of evolution from the nebulous mass down to the origin of the planets. The few applications that are made are practically identical with the Laplacian hypothesis.

PLANETESIMAL HYPOTHESIS.

This hypothesis, developed by Dr. Thomas C. Chamberlin and Dr. F. R. Moulton,* of the University of Chicago has only been before the public about eight years, and because of its newness is very little understood by most people. The following is a summary of the hypothesis:

The planetesimal hypothesis thus assumes that the solar system was derived from a nebula of the most common type, the spiral, and that the matter of this parent nebula was in a finely divided solid or liquid state before aggregation, in harmony with the continuous spectra of spiral nebulae. It regards the knots of the nebula as the nuclei of the future planets, and the nebulous haze as matter to be added to these nuclei to form the planets. It assumes that both the knots and the particles of the nebulous haze moved about the central mass in elliptical orbits of considerable, but not excessive, eccentricity. It postulates a simple mode of origin of the nebula connected with the not improbable event of a close approach of the ancestral sun to another large body, but the main hypothesis is not dependent on this postulate.

It assigns the gathering-in of the planetesimals to the crossing of the eliptical orbits in the course of their inevitable shiftings. Out of this process and its antecedents, it develops consistent views of the requisite distribution of mass and momentum, of the spacing out of the planets, of their directions of rotation, of their variations of mass, of their varying densities, and of other pecularities.

It deduces a relatively slow growth of the earth, with a rising internal temperature developed in the central parts and creeping outward. With such a mode of growth, the stages of the earth's early history necessarily depart widely from those postulated by the Laplacian and the meteoritic hypotheses.

Composition and Condition of the Earth's Interior.

Many attempts have been made by eminent authorities to arrive at some satisfactory conclusion as to the condition of the interior of the earth, because if this information were had it would be an easy matter to explain the causes of volcanic action. None of the hypotheses advanced up to the present time entirely satisfy all the conditions of the problems, but new discoveries in chemistry and physics may eventually offer a true solution of volcanic action, and when it is at last discovered may combine many of the principles which now seem to be peculiar to different hypotheses.

Two problems present themselves in a discussion of the nature and condition of the earth's interior; namely, its composition and its physical condition.

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*Chamberlin and Salisbury, Geology, vol. II, p. 81.

PROBABLE COMPOSITION OF THE EARTH'S INTERIOR.

Only a very small and almost infinitesimal part of the earth's mass can be subjected to direct examination. The distance from the surface to the center of the earth is approximately 4,000 miles, while the deepest mines only penetrate about 5,200 feet from the surface and the deepest boring in the world, in South Africa, attained only a depth of a little over 6,000 feet. Although we are not able to make direct investigations of the composition, nature, or physical condition of the internal portions of the earth, yet there are a number of facts from which we may draw important inferences.

Among the most important of these facts to the theorist is the weight of the earth. Various methods have been devised by the physicist and astronomer for determining this factor, and the conclusions arrived at by different methods agree so closely that there is little room for doubt as to the accuracy of the results. C. U. Boys computes the earth to be 5.527 times as heavy as a globe of water equal in size to that of the earth.

Inasmuch as the density of the material composing the crust of the earth according to Lunn is approximately 2.8 times that of water, a definite conclusion is reached that the interior portions of the earth are of far greater density than the exterior portions. Laplace proposed the hypothesis that the increase of the square of the density is proportional to the increase of the pressure, which gives a density of 10.74 at the center.

In attempting to account for the increased density of the interior of the earth over that of the exterior, two conflicting hypotheses have arisen. One hypothesis, supported by a few authorities, contends that the materials under tremendous pressure yield, and their particles are compelled to pack themselves, and thereby occupy less space than at the surface. There is one serious objection to this hypothesis, which its supporters are not able to surmount altogether, in that experiments disprove the idea of high compressibility of solid substances.

Since all experiments tend to prove that solid bodies yield to pressure up to a certain limit and no farther, most authorities conclude that the interior portions of the earth are composed of different materials from those which commonly occur near the surface. To substantiate further their views the supporters of the second hypothesis refer to the materials ejected by volcanoes and to the relation between the earth and other planets.

A physical and chemical analysis of the material ejected from different volcanic vents over the earth proves that even at very moderate depths there exist substances differing greatly in density and chemical

composition. According to Judd the lightest lavas have a specific gravity of 2.3, and the heaviest over 3. The lighter lavas are acidic and contain from 62-78 per cent silica and only small quantities of iron; while the heavier lavas are basic and contain 45-58 per cent silica and large quantities of iron.

Another very interesting feature is the close physical and chemical relationship between terrestrial and meteoritic rocks; for when both terrestrial and meteoric rocks are classified and placed in orderly arrangement it is found that the chemical elements which compose the two groups are identical and that these are united according to the same physical and chemical laws. Thus far no new element has been discovered in the one group that has not been found in the other. There are, however, some compounds of these elements, minerals, which occur in the earth's crust that have not been found in meteorites and also some occur in meteorites which are not known in the earth, yet of those which are common to both bodies there is agreement, even to minor details. Some of the materials carried up with the lavas from great depths in the earth's crust tend to show that at least a portion of the earth's interior consists of metallic substances uncombined with oxygen or simply alloyed with one another, the same as in meteorites.

PROBABLE PHYSICAL CONDITION OF THE EARTH'S INTERIOR.

Within the last century several tremendous volcanic eruptions have been witnessed by the human race. During each of these eruptions large masses of molten and solid materials have been seen to issue from fissures in the crust of the earth. Again, it is well known that the sun does not materially affect the diurnal temperature of the earth below a depth of about 3 feet, while seasonal changes do not affect it below a depth of about 40 feet. Yet there are also abundant observations to show that below the depth to which the influences of seasonal changes are felt the temperature increases in general at the rate of 1°F. for each 50 or 60 feet of descent. In view of these facts the question is often asked, does this same rate of increase in temperature continue to the center of the earth, and if so what is the physical condition of the earth's interior? In attempting to arrive at a satisfactory conclusion, physicists, geologists, and astronomers have formulated five hypotheses as to the physical condition of the earth's interior. The first four are based largely upon the Laplacian hypothesis, while the fifth is based upon the planetesimal hypothesis.

Liquid Interior.

Among those who first thought upon this subject, the hypothesis of an earth with an intensely heated liquid center and a solid crust was almost universally accepted.

The arguments in favor of internal liquidity are summed up as follows: (a) The apparent progressive increase of temperature is at the rate of 1°F. for each 50 or 60 feet of descent. If the temperature increases progressively as it does in the depths accessible to observation, at a depth considerably less than 50 miles from the surface, it will be sufficiently high to fuse platinum which melts at 3080° F.

(b) It has been inferred that the large number of active volcanoes scattered over the earth could not have existed and continued to pour forth the vast quantities of molten rock that have been erupted from time to time, unless they drew their supplies from an immense molten nucleus.

(c) The lavas from widely separated volcanoes exhibit a general uniformity of character, and therefore apparently emanate from a vast common source.

(d) Large areas of the earth are often affected by earthquake shocks which indicate the existence of a thin and somewhat flexible crust.

(e) Thick, extensive, marine, sedimentary formations have been elevated and then folded and crumpled. These facts also indicate to some that the crust of the earth is comparatively thin, and that it rests upon a viscous or liquid interior.

There is a diversity of opinion concerning the thickness of the crust, some maintaining that it is of insignificant thickness as compared with the bulk of the liquid interior; while others, impressed with the general stability and rigidity of the earth as a whole, maintain that it must be of considerable thickness. This hypothesis is not so prominent now as it was formerly, largely due to the fact that astronomers have proved conclusively, according to many eminent authorities, that the earth's behavior in reference to the attraction of the sun and moon and in the transmission of waves through the interior shows it to have a high rigidity, equal to that of a sphere of steel of the same dimensions.

Interposed Liquid Layer.

A series of interesting computations were made by Tait. His results, based on the observed rate of increase of temperature towards the center of the earth and the rate at which rocks conduct heat, show that a sufficient amount of the interior heat is being radiated off annually into space from each square foot of the earth's surface to raise the temperature of one and one-fourth pounds of water from the freezing point to the boiling point. A few physicists believe that a globe of liquid matter radiating its heat into space at this rate, would tend to solidify both at the surface and the center at the same time, thus forming a globe

with a solid external shell and a solid central nucleus with an interposed liquid or semi-liquid layer. In order to account for the rigidity of the earth some contend the process of radiation and solidification is almost completed and that there is probably a partial union of the interior solidified portion with the external shell.

Gaseous Interior.

Carl Ritter* was the first scientist to advance the hypothesis of a gaseous interior. He based his conclusions on observations which indicated that under high pressure above the critical temperature there is no difference between the gaseous and liquid states, and therefore according to his method of reasoning the earth consists of a gaseous center surrounded by a solid crust.

Svante A. Arrhenius,** the eminent Swedish phycicist, in support of this hypothesis points out that in fluids or gases at high temperatures, where no increase of volume takes place, the internal friction rises with the temperature.

By experiment and deduction we know that all the rocks of the earth's crust can be melted into liquids and at still higher temperatures converted into gases. Because of these facts Professor Arrhenius concluded that the crust of the earth is solid to a depth of about 40 kilometers, where there is a temperature of about 1,200° C. and a pressure of about 10,840 atmospheres. Three hundred kilometers beyond this depth, the temperature must exceed the critical temperature of all known substances, and therefore at this point the liquid magma passes gradually to a gaseous magma subject to extremely high pressure. Because of the high temperatures and pressures that prevail in the earth's interior the gases are altogether different from what we ordinarily understand by gas, and the density, compressibility, and viscosity of such substances are of such a high order that they may be regarded as solid bodies.

Granting that matter in the earth's interior may exist in a gaseous or potentially gaseous condition, it has been demonstrated that at least some hot gases can cool into molten liquids, which in turn change into solids on further cooling. It is not illogical then to suppose that the gases on escaping to the cooler surface will be gradually and successively converted into all known primary forms of minerals, water, and gases as they approach the outer crust and atmosphere.

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*Weidemann's Annalen der Physik and Chimie V. (1878) pp. 405,543; VI. (1879) p. 135; VII. (1879) p. 304; VIII. (1879) p. 157.

**Zur Physik des Vulcanismus, Geol. Foren. i Stockholm Forhandl. XXII. 1900, pp. 395-419.

Solid Interior.

The prevailing opinion among authorities of the Laplacian school of the present day is that the earth although highly heated is as a whole perfectly solid from the surface to the center.

The following arguments are used in support of this hypothesis: Lord Kelvin* in 1862 came to the conclusion that the earth's interior must be very rigid in order to maintain its shape under the great strain of the tide-producing force of the moon and sun. He writes that

> were the crust of continuous steel and 500 kilometers thick, it would yield very nearly as much as if it were india-rubber to the deforming influences of centrifugal force and of the sun's and moon's attractions.**

and therefore there would be no perceptible tidal waves. Lord Kelvin also believed that the rotary motion of the earth proved the interior to be solid. For illustration, he demonstrated that a boiled egg, which is essentially a solid is easily spinned upon its end while the internal friction of the liquid contents of a raw egg quickly stops any rotary motion which is imparted to it. Upon the same grounds he argues that had the earth's interior possessed the properties of a liquid, rotation would have been impossible.

Solid Interior With Scattered Pockets of Lava.

This is an aliquot part of the planetesimal hypothesis which has been worked out by Professors Chamberlin and Moulton* of the University of Chicago within the last few years. The following quotation gives a good summary of the probable physical condition of the earth's interior as by the planetesimal hypothesis:

> This middle zone should, under this view, experience a rising temperature. By hypothesis, this zone is composed of various kinds of matter mixed as they happen to fall in. Hence as the temperature rises, the fusion points of some of these constituents will be reached before those of others. More strictly, the temperatures at which some of these constituents will mutually dissolve one another will be reached, while other constituents remain undissolved, and thus a partial and distributed liquefaction will arise. The gases and volatile constituents in the mixed material would naturally enter largely into the liquefied portion. It is assumed that with a continued rise of temperature, the partial liquefactions would increase until the liquefied parts found means of uniting, and the lighter portions, embracing the gaseous contingent, were able to work their way toward the surface. As they rose by fusing or fluxing their way, the pressure upon them became less and less, and hence the temperature necessary for liquefaction gradually fell, leaving them a constantly renewed margin of temperature available for melting their way through the upper horizons. Thus it is conceived that these fusible and fluxing selections from the middle zone might thread their ways up to

*Proc. Roy. Soc., Apr. 1862.
**Brit. Assoc. Rep., 1876.
***Chamberlin and Salisbury, Geology, vol. I, p. 629.

the zone of fracture and thence, taking advantage of fissures and fractures, reach the surface. It is conceived that such liquefaction and extrusion would carry out from the middle zone the excess of temperature received from the deeper interior, and thus regulate its temperature and forestall general liquefaction, the zone as a whole remaining always solid. The independence of volcanoes is assigned to the independence of the liquid threads that worked their way to the surface.

Supposed Causes of Volcanic Action .

The great physical questions which bear upon the causes of vulcanism have not yet been entirely solved by the scientist. The amount of work done has been more in the nature of pioneer work rather than in the construction of any complete theory; yet many errors have been cleared away and probably the principal causes have been at least surmised, although there may be some physical principles which still remain undiscovered, or the importance of which have hitherto been overlooked.

The explanation of volcanic phenomena involves two essential elements; namely, the origin of the lavas and the forces by which the lavas are expelled.

ORIGIN OF LAVAS.

According to the Laplacian and meteoritic hypotheses the earth was in a molten condition in an early period of its history while the planetesimal hypothesis assumes that the earth was built up by the aggregation of cold, solid particles and that it was never completely molten.

The supporters of the Laplacian hypothesis are divided into four classes in regard to the condition of the earth's interior, as has already been stated. The first class believes the interior to be molten, the second, that there is an intermediate liquid mass between a solid interior and a solid exterior, the third class holds that the interior is gaseous, while the fourth class maintains the interior to be solid but in a potentially plastic condition.

As a result of these conflicting opinions two different schools which also disagree in respect to the planetesimal hypothesis were formed. Those who believe the lavas to be residual portions of the original molten mass, and those who believe that the interior has solidified and that the lavas are formed from local melting of rock.

Original Lavas.

The earlier writers on vulcanism were practically a unit on the idea that the interior of the earth is in a molten condition. The prevailing opinion among supporters of this view, that the volcano is directly connected with the liquid or gaseous interior, is nothing more than a natural assumption. The rigidity of the earth, however, as proved by astronomy and the independence of lava in adjacent vents is contradic-

tory to such a conception. In order to account for these conditions, many have suggested that the interior has become almost entirely solidified leaving numerous liquid masses scattered through it.

Secondary Lavas.

Much additional information pertaining to volcanic activity has been obtained since the early days of the Laplacian hypothesis, and as a result of these new data several hypotheses have been advanced to account for the source of the lava. These hypotheses will be referred to briefly.

Chemical Hypothesis.—During the early stages in the study of volcanoes Davy and Daubeny contended that the interior rocks were not originally oxidized and that the penetration of air and water caused oxidation to take place with the generation of the amount of heat necessary to liquefy the surrounding rocks. Modern thermo-chemistry apparently disproves this and the hypothesis is a matter of history.

Mechanical hypothesis.—Mallet* believed that the friction between the rocks caused by the folding or faulting of the earth's crust was sufficient to generate the required amount of heat to bring on volcanic conditions. Such movements unquestionably produce heat and the metamorphic condition of some rocks certainly favor Mallet's contention. On the other hand, folding and faulting take place only in the zone of fracture, which is much more shallow than the actual source of supply of lava. Besides, volcanoes are not found in the Appalachian Mountains where there has been intense folding and much faulting. In fact,

> Extrusions seem rather more common with faulted ranges where crushing is less notable and where surface tension replaces compression.**

Steam hypothesis.—Laboratory experiments have proved that moderately heated igneous rocks when brought into contact with water tend to develop gases closely similar in character to those which are emitted by active volcanoes. Inasmuch as volcanic gases are believed to be the chief agents in producing volcanic explosions some scientists believe that water and its absorbed gases, penetrating through the fissures and pores of the outer crust either by osmotic pressure or capillary attraction, come in contact with heated rocks and are absorbed by them, rendering the whole liquid, and that the lava thus formed is then forced to the surface. Chamberlin and Salisbury*** and others believe that the gases were entrapped when the globe was built up of planetesimal matter, while some scientists of the Laplacian school believe that the original molten globe absorbed gases from the primitive atmosphere and retained them until the time of their eruption.

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*Mallet, Robert, on volcanic energy, Trans. Roy, Philos, Soc., 1873.
**Chamberlin and Salisbury, Geology vol. I, p. 629.
***Chamberlin and Salisbury, Geology vol. 1, pp. 621-622.

Gautier, Burn and a few others contend that the gases in the lavas are formed by reactions within the rocks themselves because the crystals of deep-seated igneous rocks contain gas and liquid-filled cavities, due to the presence of gas or steam in the crystal at the time of consolidation. Some appalling results were obtained by Gautier in his attempts to illustrate the magnitude of the phenomena to which reactions may give rise. He showed that a cubic kilometer of granite is capable of yielding 26,400,000 metric tons of water and 5,293,000,000 cubic meters of hydrogen measured at ordinary temperatures. That amount of hydrogen burning, would combine with oxygen and form 4,-266,000 tons of water, making a total of approximately 30,666,000 tons of water to be derived from each kilometer of granite. These figures show that it is not necessary for the heated rocks to come into contact with inletting waters from the ocean but that the water of volcanoes, instead of being contributed by the oceans, is derived from the gases of the earth's interior.

Shaler* proposed a modification of the steam hypothesis which deserves mention. At the time of deposition all oceanic sediments are saturated with sea-water. The successive layers act as blankets to retard the escape of the excess of heat, and by the time any great thickness is attained the basal sediments become sufficiently heated by conduction from the earth's interior to generate enough steam to produce volcanic eruption.

From these discussions it is apparent that there is probably a wider variation of views in regard to the origin of steam and gases in the lava than on any other phase of vulcanism. It is admitted by all that lava in rising to the surface may encounter rocks saturated with moisture, and thereby generate some steam, but the point in dispute is the amount.

Relief of pressure hypothesis.—Experiments in the laboratory seem to prove that pressure raises the melting point of rock, and therefore even if rocks 30 miles below the surface are heated above their melting point at surface pressure they are in a solid condition because of increased pressure. If at any time the pressure is sufficiently relieved by means of denudation, faulting, anticlinal arches, or continental deformation, the rocks become liquid, according to this hypothesis.

Melting by depression hypothesis.—In certain regions great thicknesses of sediments have accumulated by the slow settling of the crust below. This accumulation of sediments obstructs the outward flow of heat, and as the lower beds saturated with water sink, they gradually become heated and finally aqueo-igneous fusion occurs. In case there is no volcanic vent to permit the escape of the lava and its steam and

*Shaler, N. S., Aspects of the earth, New York, 1889.

gases, it sometimes happens that the pressure is sufficiently great to force an eruption, which in a few instances has assumed great proportions.

Planetesimal hypothesis.—This assumes that the earth grew by slow accessions of meteoroidal or planetesimal matter and that the interior heat is due chiefly to compression by its own gravity, and therefore the internal temperature was originally distributed according to the degree of compression. That phase of the planetesimal hypothesis pertaining to the origin of lavas has already been discussed and will not be elaborated upon any further at this point.

Forces by which Lavas are Expelled.

The forces that are generally regarded as producing volcanic phenomena are the contraction of the earth, the relief of pressure, and the escape of included steam and gases.

CONTRACTION OF EARTH.

The interior heat of the earth is being conducted to the surface continually and there radiated off into space. This loss of heat causes a contraction of the cooling rocks, and warping and bulging occur in the rigid crust as a result of its attempt to conform with the shrinking interior. The compressional and tensional pressure in some cases are sufficiently great to cause folding and breaking in the rigid crust which act as a passage way for the escape of the included molten mass. The differentiation of pressure also results in movements of magma, which accounts for the outflow of lava in volcanoes where no explosive phenomena are manifested.

RELIEF OF PRESSURE.

The preponderating evidence is that recent volcanic eruptions have usually taken place in mountain ranges and plateaus that had been elevated—according to the geological time scale—only a short time previously. Dutton as a result of these observations suggested that the area immediately adjacent to active volcanoes is rising. As the surface rises, from lateral pressure or other causes, there is a proportionate relief of pressure from the underlying heated rocks. When the relief of pressure is sufficiently great the magna liquefies and consequently expands. This expansion, together with the pressure of the surrounding rocks, forces the molten lava up through any openings that are present.

ESCAPE OF INCLUDED STEAM AND GASES.

Inflated lavas, pumice, scoriae, and cinders are the typical and dominant products of explosive vulcanism, and therefore it is almost universally conceded that steam and gases are the chief agents in producing volcanic explosions. The gases usually found are water vapor,

steam, hydrogen, oxygen, nitrogen, argon, hydrogen sulphile, sulphur dioxide, carbon dioxide, carbon monoxide, hydrochloric acid, chlorine, methane, hydrofluoric acid, and silicon fluoride*. Geikie reports that potassium, iron, copper, lead, borax, and sodium have also been found with these gases. Of the total gaseous content, according to most authorities, approximately 99 per cent is water vapor.

*Clark, F. W., Bull. U. S. Geol. Survey, No. 491, p. 249.

CHAPTER II.

GENERAL ACCOUNT OF VOLCANIC DUST.

ORIGIN.

Volcanic dust, commonly spoken of as volcanic ash, is a form of rock composed of a finely powdered, light, porus, siliceous material blown from volcanoes. It is a product of the explosive type of volcanoes such as Mount Pelee, Krakatoa, and Mount Katmai, and is really an extreme case where the contained steam and other gases are sufficient upon relief of pressure as the lava nears the surface, to atomize the lava and blow it out as dust.

DISTRIBUTION.

There is probably no portion of the earth's surface that has not been subjected in past ages to one or more showers of volcanic dust. This phase of the subject has already been discussed at some length in the section on explosive type of volcanoes and repetition is here unnecessary.

PHYSICAL AND CHEMICAL PROPERTIES.

The leading physical properties of volcanic dust are its color and the angular character of the flakes of glass of which it is largely composed. In appearance it closely resembles chalk and also gypsite, a form of weathered gypsum. The deposits of volcanic dust are usually more or less adulterated with other substances and therefore no two beds have exactly the same tint, as the color varies considerably. The colors are usually of light gray, but some are bluish gray, others are dark gray, and still others which contain some oxidized iron have a slightly reddish color. The individual flakes are usually too small to be seen by the unaided eye, but when examined under a miscroscope they are found to have a glimmering, glistening, and more or less vitreous appearance and are seen to consist of numerous angular, almost transparent, and usually noncrystalline flakes and shreds of glass, which frequently contain irregular cavities and tubes. Artificial volcanic dust may be almost precisely duplicated by grinding ordinary glass.

Volcanic dust does not vary greatly in physical and chemical properties, deposits in widely distributed areas showing a marked similarity. It has a specific gravity of about 2.5. This specific gravity readily distinguishes it from diatomaceous earth, which is much lighter. These two substances closely resemble one another in other respects. Dry diatomaceous earth will float for a while on water until it becomes "water logged," while on the other hand, volcanic dust will sink immediately.

Simple chemical reactions for the detection of volcanic dust are few. Phosphoric acid is the only acid that acts to any appreciable extent on volcanic dust. This dust yields a silica bead with a phosphorus salt, and aluminum blue is given with cobalt nitrate. It yields a small amount of water in a closed tube; gives but a feeble soda flame; and shows only a slight test for iron with potassium ferrocyanide and ammonium sulphocyanate.

CHEMICAL COMPOSITION.

The average chemical composition of volcanic dust is rather constant in its essential elements, and only the accessories vary to any noticeable degree. There is a slight variation, however, and the different analyses given below, together with the analyses of the dust in the different deposits in Oklahoma in Chapter III of this report will give the chemical composition of volcanic dust in widely scattered areas over the earth.

*Analysis of volcanic ash from Ravalli County, Montana.**

H_2O	3.10
SiO	68.49
$AL_2O_3 + Fe_2O_3$	21.35
MgO	.39
Na_2O	3.487
K_2O	4.169
Total	99.986

*Analysis of volcanic ash from Gallatin County, Montana.**

SiO_2	68.68
AL_2O_3	12.69
Fe_2O_3	1.14
FeO	1.17
MnO	Trace
MgO	1.14
CaO	1.11
Na_2O	1.32

K_2O	5.58
Li_2O	....
SO_3	....
Ignition	7.99
Total	100.73

*Analysis of volcanic ash from La Soufriere.**

SiO_2	55.08
AL_2O_3	18.00
Fe_2O_3	2.46
FeO	4.57
MgO	3.34
CaO	7.74
Na_2O	3.45
K_2O	0.65
H_2O at 100° C	0.66
H_2O above 100° C	1.39
TiO	0.80
ZrO_2	(?)
CO_2	None
P_2O_5	0.17
SO_3	0.24
Cl.	None
S (included in Fe_7S_8)	0.36
NiO	None
MnO	0.21
BaO	Trace
SrO	None
LiO_2	Faint trace
Fe_7S_8 (?)	0.91
Total	99.67

ECONOMIC VALUE.

Volcanic dust, although only recently considered as a commercial commodity, has varied and extensive uses. It is at present used largely for abrasive purposes in the form of polishing powders, scouring soaps, etc., but, because of its pumaceous condition, it is used in the manufacture of dynamite, and as a holder of nitroglycerine; and also because of lightness and porosity it is a good non-conductor of heat, and for this reason is being used as packing material for safes, steam pipes,

*Rowe, Jesse Perry, Some volcanic ash beds of Montana, Bull. Uni. of Mont., No. 17, 1903, pp. 9, 10.

and boilers and as fire-proof building material. According to authoritative reports it is said that it may be used with satisfactory results as a substitute for sand in paint where the surface coated is exposed to the weather. In Germany its field of usefulness is still more extensive. It is there used as an absorbent for liquid manures in preparation of artificial fertilizers, and in the manufacture of water glass, of various cements, of glazing tiles, of artificial stone, of ultramarine, and various pigments of analine and alizarine colors of paper, sealing wax, fireworks, gutta percha, and many other articles.

It is a well known fact that volcanic dust is an excellent fertilizer. Wherever this dust has spread over an area with an average rainfall there is a very abundant and prolific vegetation. Along certain parts of the Rocky Mountain plains and over scattered areas of the Great Basin the country in places is literally covered with volcanic dust, and wherever this volcanic soil is subject to irrigation no better or more fertile soil can be found. The very beauty of Java, the "garden spot of the world" is due to the rich, fertile soil formed largely from volcanic dust and other eruptive matter that have fallen over the island at different periods in former volcanic eruptions.

CHAPTER III.

OCCURRENCE OF VOLCANIC DUST IN OKLAHOMA.

INTRODUCTION.

In the preceding chapters were discussed the different types of volcanoes, their nature and origin, also the characteristics and economic value of volcanic dust. The present chapter gives briefly the location, accessibility, quantity, and quality of the different volcanic dust deposits

Fig. 1. Showing location of known deposits of volcanic dust in Oklahoma.

that are known to exist in Oklahoma. The source of this dust and the means of its transportation from the place of eruption to its present location and its stratigraphic position are also discussed.

The distribution of volcanic dust in Oklahoma is shown in figure 1. In this map, however, only those localities are shown in which deposits of volcanic dust are known to exist. As has been stated above under the discussion on the distribution of volcanic dust, there is little doubt but that this material occurs in small quantities finely disseminated through the surface soil over the entire State. There are only a few localities, however, in which deposits of any considerable magnitude are known.

LOCATION OF DEPOSITS.

Deposits Northeast of Gate.

The largest known deposit of volcanic dust in Oklahoma occurs in sec. 10, T. 28 N., R. 26 W., which is near the boundary line between Harper and Beaver counties and about 6 miles north and 2½ miles east of Gate. The principal outcrops of this deposit occur along the east bank of a small ravine in the west central part of the section. (Pl. VI A.) The dust is exposed north and south along the stream bank for a distance of about 1,800 feet. For 600 to 900 feet along the center of this outcrop the dust is about 9 feet thick, but there is a gradual thinning out in both directions from the center. Along the outcrop the dust is covered with only 6 feet of soil. To the eastward the surface is level for some distance and the volcanic dust is known to extend in that direction at least half a mile, because prairie dogs have brought it to the surface. To the westward, in sec. 9, volcanic dust outcrops along the banks of the small ravine that flows to the north.

The volcanic dust in these outcrops is of a dark gray color at the top, but whitens considerably toward the bottom. This is because the dust at the top contains more sand, small quartzite pebbles, and other impurities than the bottom of the deposit. This dust rests directly upon a reddish brown, sandy clay which was but slightly eroded before the dust was deposited, as there is a sharp contact with very little variation in altitude in the line of contact.

About 2 miles east of this area the small hills are capped with a layer of rock probably 3 to 5 feet in thickness, which is composed of volcanic dust mixed with sand. (Pl. VI B.) This formation resembles a sandstone, but the ash intermingled is easily seen when examined closely.

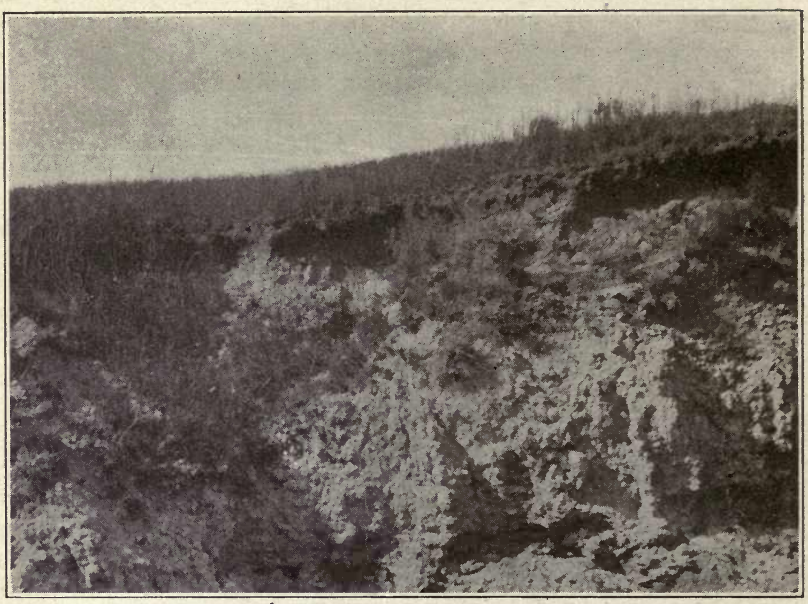

Plate VI. (a) Volcanic dust 9 1-2 miles northeast of Gate.

Plate VI. (b) Sandstone and volcanic dust mixed, capping hills 12 miles northeast of Gate.

Plate VII. (a) Deposit of dust with contact clearly shown, northeast of Gate.

Plate VII. (b) Nodules of dust in shale, northeast of Gate.

Plate VIII. (a) A close view of volcanic dust, showing grassed surface—location west of Woodward.

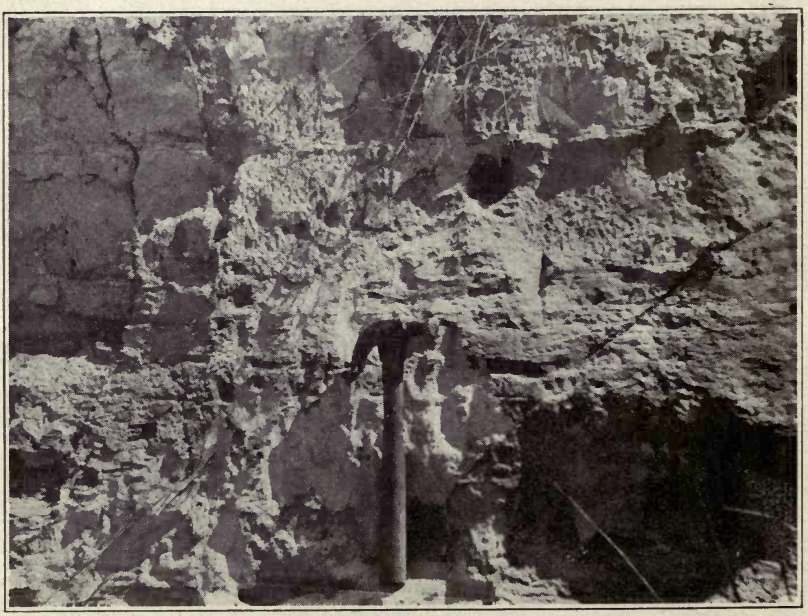

Plate VIII. (b) A view at close range, north of Custer City.

Another prominent dust deposit occurs near the center of the northwest quarter of sec. 10, T. 5 N., R. 28 W., and only about 1¼ miles southwest of the first deposit described. The deposit at this place is about 10 feet thick. (Pl. VII A.) It outcrops on the surface but the top 3 feet contain some pebbles of impure limestone, quartzites, and thin seams of sands and other impurities common to the Pleistocene formations. The pebbles vary considerably in size, most of them being the size of small marbles, but one pebble or boulder 1 foot in diameter was seen. The bottom 7 feet of the deposit is almost free from impurities. It rests on a sandstone of very irregular grain, but, like the other deposit to the east, the contact line is very sharp.

The volcanic dust in this deposit occurs in a ridge that runs north from the small canyon to the south. The dust is exposed only over a territory about 120 feet wide east and west, extending back along the ridge for a distance of about 450 feet. Farther to the north there is no surface indication of its presence, but there is no evidence that it does not occur immediately under the surface.

About 300 feet southeast of the above deposit is another small bluff in which volcanic dust occurs. At this point the dust is very irregular in thickness. On the west end it is about 4 feet thick, but within the first 20 feet to the eastward it thins down and has a thickness of only one foot. From this point to the eastward, in a distance of 60 feet, it attains a maximum thickness of 7 feet. Apparently the dust extends only a short distance back in the ridge.

Another deposit of dust outcrops up the canyon about 1,200 feet due east of the deposit just described. It is exposed for a distance of about 150 feet and is apparently about 10 feet thick. At the outcrop the deposit is covered with about 6 to 8 feet of surface soil, but within 225 feet it extends under an embankment.

There were a few additional deposits of volcanic dust noticed in the general vicinity of Gate, but they were too small to merit further notice.

The chemical composition of the volcanic dust occurring in the deposits described above is shown by the following analysis:*

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*All analyses in this chapter were made by F. Aurin, Chemist for the Oklahoma Geological Survey.

Analysis of volcanic dust at Gate Oklahoma.

SiO_2	72.18
Fe_2O_3, Al_2O_3	14.5
CaO	.54
SO_3	.597
Organic matter	5.05
Na_2, K_2O, and MgO not determined.	

About 4 miles west of the area discussed above, in the east central part of the NW. ¼ sec. 1, T. 5 N., R. 27 W., occurs a 12 foot deposit of material which resembles volcanic dust. Its principal constituents are CaO, 35.55 per cent; Fe_2O_3 and Al_2O_3, 23.49 per cent; and SiO_2, 10.68 per cent. This material when studied under the miscroscope shows numerous diatoms and Dr. Van Vleet, head of the Department of Botany in the University of Oklahoma, believes that practically all of the silica in this material is accounted for by the silica in the diatoms. The presence of these diatoms indicates that this calcareous diatomaceous earth was deposited under water.

Owing to the angular nature and hardness of its component particles, diatomaceous earth has valuable abrasive properties and in most cases may be used as a substitute for volcanic dust. The deposit above is the only deposit of diatomaceous earth that is known to exist in the State of Oklahoma. It does not at present have any commercial value, however, because in the first place it contains too many impurities, and in the second place it is not accessible to railroad transportation.

At first the writer was inclined to believe that this deposit occurs on an old extinct volcanic cone, because the outcropping strata dip about 15° in every direction from a central excavation which has the appearance of an old crater. The diameter of the central depression is about 750 feet but there is no evidence of any former volcanic activity. Inasmuch as the strata lie conformably on one another, and have never been affected any by volcanic matter the dome structure is due to a slight local uprising of the surface formations, while the excavation is due to surface erosion.

Deposits west of Woodward.

An important area of volcanic dust occurs about 6 miles west and 2 miles north of Woodward, in sec. 13, T. 23 N., R. 22 W. Near the central part of the section a deposit of volcanic dust outcrops for about 300 feet along the north side of a ravine that runs east and west. The exposures along this ravine show the deposit to have a thickness of about

6 feet. The extent of this deposit was not determined because, to the northward it is covered with a few feet of surface soil and does not outcrop anywhere. To the southward a short distance in the south central part of the same section an 8-foot deposit outcrops along the east bank of a small ravine for about 600 feet. This deposit is probably a continuation of the one to the north and has been cut through by small streams. The dust here is very near the surface, and sage brush which grows profusely along the west side of the ravine, has been displaced on the east bank by grass. (Pl. VIIIA).

The volcanic dust in this locality may not lie in one continuous deposit, but the different outcrops along the ravines occur at about the same elevation and horizon. There are some small exposures of volcanic dust in the ravines just east of the area above described, while to the south in the northeast corner of sec. 24, considerable quantities of volcanic dust outcrop. This dust also extends slightly across the township line to the east into sec. 19.

The volcanic dust in this area usually rests on a loose sandstone. The bedding plane, however, is very irregular and along the outcrop in the deposit near the central part of sec. 13, there is a sudden break of about 12 feet. This fact indicates that the dust was deposited on an area that had been previously subjected to erosion.

The color of the dust in the deposits above is grayish-white, and the following analysis shows that the chemical composition is about the same as that northeast of Gate.

Deposits northeast of Custer City.

The most accessible and therefore probably the most important volcanic dust deposit in Oklahoma occurs a short distance northeast of Custer City. The principal deposit in this area is located in the southeast part of sec. 15, T. 14 N., R. 16 W. A good exposure of this deposit is seen on the south side of a ravine just west of the section line and about 750 feet north of the south of the section. (Pl. VIII B). At the line of outcrop the thickness of the volcanic dust is from 8 to 12 feet. The extent of this bed is unknown, as the outcrop is only exposed for a short distance. A couple of dug wells nearby, and also a few test holes, however, reveal the presence of dust under a large portion of the southeast part of this section. In a dug well a short distance northwest of the outcrop 18 feet of volcanic dust was encountered, but this is covered with about 9 feet of surface soil. Test holes in other places found volcanic dust, but in every instance several feet of surface soil overlie the dust.

In order to handle this dust the surface soil must be removed and this necessitates too great an outlay of money to make the handling of

this material profitable. Only that dust at the outcrop may be worked at a profit under the existing market values.

Small outcrops of volcanic dust occur along some of the ravines in sec. 14, and since all of these exposures are found to be at about the same horizon, it is very likely that the dust in the different deposits was laid down at the same time.

The dust in this area has about the same color and other physical characteristics as that at Gate and Woodward. The chemical composition of this dust is shown by the following chemical analysis:

Analysis of volcanic dust northeast of Custer City.

SiO_2	70.12
Fe_2O_3, Al_2O_3	15.8
MgO	.23
CaO	.52
Na_2O	4.429
K_2O	3.016
SO_3	1.168
Organic matter	6.42

Deposit northwest of Wetumka.

One of the surprises of the field work was the discovery of a deposit of volcanic dust about 6 miles north and 2 miles west of Wetumka in sec. 17, T. 10 N., R. 10 W. The dust outcrops on a small promontory which projects to the southward into a small valley. The deposit has a maximum thickness of about 12 feet but averages only about 5 feet. The dust apparently covers only a small area as no evidence of any other outcrops was observed in that locality.

The analysis below shows that the chemical composition of the dust in this deposit is very similar to the composition of that which occurs in the western part of the State. It also has practically the same physical characteristics except that the grains are smaller.

Although this deposit does not contain nearly so much volcanic dust as some of the other deposits in the State and occurs several miles from railroad transportation, yet it is the only dust in the State that is being worked into commercial products. This dust is hauled to Okemah in wagons and there shipped to the Big Chief Chemical Company at Oklahoma City. The principal constituent in the excellent scouring powder Big Chief, put out by this Company is volcanic dust.

Deposit at Stigler.

The point farthest east in which any deposit of volcanic dust is

known to exist occurs at the north edge of the town of Stigler in sec. 7, T. 9 N., R. 21 E. A small outcrop of some of this deposit lies on the south bank of a small stream running east along the north side of town. The dust at this point is only 4 or 5 feet thick and contains a large amount of foreign matter that has been deposited in it by circulating water.

Several test holes and dug wells in this vicinity prove that the deposit of dust thickens to the south and southwest and that it underlies an area of about 200 acres. A surface soil however overlies this deposit and therefore in all probability it will not be developed within the near future.

Miscellaneous Deposits.

There are several small deposits of volcanic dust occurring in different areas scattered over the State that are of interest, but they are not so important as those that have already been discussed and only the more important ones will be referred to at this time. A good-sized deposit outcrops along some of the ravines in sec. 6, T. 15 N., R 15 W. The dust in this area is of average purity and in places is 10 to 15 feet thick. The deposit occurs in a rough broken country and is about 6 miles from a railroad. Another small deposit of dust occurs about 2 miles northwest of Southard. This deposit outcrops in a deep ravine and although it is within a mile of a railroad yet it is inaccessible and is also covered with several feet of surface soil.

A number of small deposits of volcanic dust are known to occur from the general area around Alva east to Newkirk and south to Watonga and Kingfisher. The dust in this territory usually occurs in thin blankets scattered over considerable areas but it seldom exists in beds with a thickness of more than 1 or 2 feet. Very frequently also nodules of almost pure volcanic dust are observed in the surface formations. (Pl. VII B).

The writer was unable to discover any deposits of volcanic dust between the general area referred to above and the territory around Okemah. Within all probability volcanic dust does really exist in small quantities over this area but thus far no deposits have been reported to the Survey office. A small deposit of volcanic dust occurs 6 miles west of Okemah. Another is located near Dustin.

The principal volcanic dust deposits in Oklahoma occur in the northwest and east central portions of the State. The writer does not know of any particular reason why dust deposits may not exist in other portions of the State.

Analysis of volcanic dust west of Tangier.

SiO_2	68.64
Fe_2O_3, Al_2O_3	14.64
MgO	.23
CaO	.9
SO_3	2.45
Organic matter	9.88

Na_2 and K_2O not determined.

Analysis of volcanic dust near Thomas.

SiO_2	71.68
Fe_2O_3, Al_2O_3	14.92
CaO	.76
So_3	.65
Organic matter	5.57

MgO, Na_2O, and K_2O not determined.

Analysis of volcanic dust near Alva.

SiO_2	79.52
Fe_2O_3, Al_2O_3	11.56
CaO	1.08
SO_3	.78
Organic matter	3.06

MgO, Na_2O, and K_2O not determined.

Analysis of volcanic dust near Darrow.

SiO_2	70.44
Fe_2O_3, Al_2O_3	16.12
CaO	.58
SO_3	1.26
Organic matter	6.17

MgO, Na_2O, and K_2O not determined.

Analysis of volcanic dust 7 miles south of Okemah.

$Si0_2$	68.823
Fe_2O_3, Al_2O_3	13.316
MgO	.192
CaO	.96
Na_2O	3.231
K_2O	3.572
SO_3	2.13
Organic matter	8.223

THE PROBABLE SOURCE OF VOLCANIC DUST IN OKLAHOMA.

The stratigraphic position and manner of occurrence of the different deposits of volcanic dust in western Oklahoma, as shown in the discussion above, show some of them to be above the Permian Redbeds and Pliocene formations, and therefore the volcanic eruptions which formed this dust must have taken place after the Redbeds and Pliocene formations were laid down. In seeking the ultimate source of these deposits it is found that during either the late Tertiary or Pliocene age when these formations were deposited, there was no volcanic activity in what is now Oklahoma. There is no evidence whatever of any eruptions in the Wichita, Arbuckle, or Ouachita mountains, or the Ozark uplift during this time. There is, however, a deposit of basaltic lava known as the Black Mesa that occurs in the extreme northwestern part of the State, but judging from the nature of this deposit there is little doubt but that it is due to a quiet uprising of lava. We are therefore compelled to look elsewhere for the source of the volcanic dust.

Naturally we turn our eyes to the Rocky Mountains, where active volcanoes are known to have existed during this period. Here, however, we are confronted with the problem of distance, which may seem to some prohibitive. From eastern Oklahoma to the Rocky Mountain region is approximately 600 miles; while it is a still greater distance to Old Mexico or to the north Rocky Mountain region. It is possible that the volcanic dust of Oklahoma was carried that great a distance.

It has already been stated in this report that after the eruption of Mount Katmai in June, 1912, dust fell at Ketchikau which is 900 miles from the volcano. The volcanic dust from the explosion of Krakatoa was shot up into the air 17 to 23 miles and the coloring effects on the sunsets indicated that some of this dust traveled around the earth in fifteen days, and some authorities estimate that a part of the dust remained in the air at least three years after the explosion. In the year 1783 during the eruption of Skapter-Jokulu in Iceland there was an enormous amount of fine dust ejected into the atmosphere. At points 600 miles away from the scene of eruption the ash fell in such great quantities as to destroy the crops. Several other instances might be cited in which volcanic dust fell as much as 700 and 800 miles from the scene of eruption.

When we consider that the distance between points in Oklahoma and the volcanic area of the Rocky Mountain region is no greater than those referred to above, we may therefore conclude that, so far as distance is concerned, our volcanic dust could have come from New Mexico or Colorado, or even from points farther removed.

It will be of interest at this point to refer briefly to some of the old extinct volcanic cones of New Mexico and Colorado, some of which are probably the source of at least a portion of our volcanic dust.

One of the principal volcanic areas in this region occurs in the west-central part of New Mexico in the region of Mount Taylor. There are between 100 and 200 cinder cones on the Mount Taylor mesa. In speaking of this area Johnson* says: "In conclusion, it appears that the various phenomena associated with the buttes of Mount Taylor region accord perfectly with that hypothesis which interprets them as true volcanic necks, but do not admit of their interpretation as remnants of flows, sills or laccolithe." The distribution of these extinct volcanic vents upon the mesa is very irregular. In some places they are thickly clustered together; in others they are separated by intervals of 4 or 5 miles. The most prominent cone in this region is Mount Taylor, which has an elevation of 11,390 feet above the sea. The mesa from which it rises is about 47 miles long and 23 miles wide. Mount Taylor is composed almost entirely of lava, which rose through the single opening and built up a prominent cone with a large crater in the summit.

There are two moderately recent volcanoes in northeastern New Mexico near Fort Union. The one situated about 13 miles north of Fort Union is Ocate crater, while the other, 7 miles east of the same town is unnamed. Professor Israel C. Russell and Professor J. J. Stevenson studied Ocate crater in 1878. It is a moderately well preserved crater of basaltic rock, and has a truncated cone with a slope of not far from 20°. The crater to the east of Fort Union is better preserved than Ocate crater. The predominant rock in this cone is a hard, steel-gray basalt.

The Spanish Peaks, situated in the southeastern part of Colorado, about 60 miles south of Pueblo, are probably the best example of extinct volcanic cones in this general area. The two prominent peaks rise 12,720 and 13,620 feet, respectively, above the sea. In discussing these peaks Russell** says they

> rise abruptly from a region of comparatively mild relief and on account of their isolated position are impressive from whatever direction they are seen, not on account of their height, but because of their sculpturing and varied colors. They are sharp, conical peaks from which radiate a large number of narrow, wall-like ridges formed by dikes which mark the courses of fissures. These dikes, now weathered out so as to stand in bold relief, extend from the plain by the mountains to their very summits. It seems to the present writer, from a study of the region adjacent to the

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*Johnson, Douglas Wilson, Volcanic necks of the Mount Taylor region, New Mexico, Bull. Geol. Soc. Am. vol. 18, p. 324.

**Russell, D. C., volcanoes of North America, pp. 260-262.

Spanish peaks, as well as from descriptions just cited, 5,000 or 6,000 feet would be a small measure of the amount of surface material that has been carried away. The Spanish peaks have not only been reduced to the condition of volcanic necks, like those of the Mount Taylor region, New Mexico, referred to above, but erosion has been continued until the necks themselves have been removed, and the very roots of the volcano to which they lead laid bare.

There are several other extinct volcanic cones in this general area, but further enumeration is needless. Northern Mexico, the Great Basin area, and the northern Rocky Mountain states contain a large number of extinct volcanoes which may have contributed some of the volcanic dust in the State, but those in New Mexico and Colorado undoubtedly could have contributed the larger amount so far as distance is concerned.

As to the geologic age of the volcanic dust in Oklahoma, there are at present no known facts to hinder them from being all regarded as of the same age and being referred to the time of eruptions in the general Rocky Mountain region. In speaking of the Zuni Plateau region Dutton* regards some of the eruptions as probable middle Eocene while the youngest may have been witnessed by the earliest Spanish visitors to this region. Of the eruptions near Mount Taylor the same author says that he believes the earliest occurred in nearly Miocene and that they lasted through a long period of time.**

The deposits of volcanic dust in the west-central part of the State rest on beds of Permian and of Cretaceous ages, while in the eastern part they occur in Pennsylvanian formations. In places, furthermore, the dust rests on fresh water deposits that are usually regarded as of Miocene or Pliocene age and, hence, the dust must be Miocene or Pliocene or younger. It may be concluded then that the eruptions in late Tertiary or Pleistocene times in the general Rocky Mountain region gave rise to the volcanic dust of this State.

By another line of reasoning we are forced to the same conclusion. There has been no volcanic activity worthy of the name east of the Rocky Mountains in or since the Tertiary times or even for long ages prior to Tertiary. In fact the whole Mississippi Valley is characterized negatively by the absence of volcanic activity and this, if nothing else, forces one to look to the westward for the source of the State's volcanic dust.

Again, it is a fair assumption that the volcanic dust was carried

*Dutton, C. E., Mount Taylor and the Zuni Plateau, 6th Ann. Rept. U. S. Geol. Survey, 1885, p. 119.

**Idem, p. 178.

Table Showing Character of Volcanic Dust.

Sample No.	SIZE OF GRAINS			SHAPE OF GRAINS	LOCALITY	REMARKS
	VARIATION					
	Largest Size	Smallest Size	AVERAGE			
No. 1.	.143 mm.	.011 mm.	.044 mm.	Angular and Lenticular	Northeast of Gate, Okla.	Many lenticular fragments. Few angular fragments.
No, 2.	.220 mm.	.022 mm.	.110 mm.	Angular	Northeast of Custer City, Okla.	Many large angular fragments. Few small angular fragments.
No. 3.	.253 mm.	.011 mm.	.055 mm.	Angular	South of Okemah, Okla.	Many large angular fragments. Many small angular fragments.
No. 4.	.077 mm.	.005 mm.	.0275 mm	Angular	Near Stigler, Okla.	Few large angular fragments. Many small angular fragments.

to its present position by prevailing, that is, southwest, winds. For there are sound reasons for believing that the prevailing winds of the present are not essentially different from those of late Tertiary and Pleistocene times. Northeast, east, or southeast winds in the southern plains are exceptional, prevailing for only a short time, even when they occur. There seems to be, therefore, no escape from the conclusion that our volcanic dust came from the southwest or west in late Tertiary or Pleistocene times.

If the volcanic dust in Oklahoma were carried from the Rocky Mountain region by the prevailing southwest, or possibly west winds, the coarser dust should settle first, and therefore each succeeding deposit to the eastward should be finer grained than those to the westward. The following table by Mr. Aurin shows that with the exception of the deposit northeast of Gate, Oklahoma, the grains decrease in size from the west to the east, and this tends to confirm the conclusion above. The size of the grains in the deposit northeast of Gate indicates that probably the dust in this area represents an independent eruption.

Although the winds undoubtedly have been the principal factor in the distribution of volcanic dust in Oklahoma, yet water has probably assisted in many cases. In a few deposits visited by the writer, the nature of the surrounding country, the plane of contact, and the overlying and underlying formations all indicate that the dust was laid down in some body of water, presumably a fresh water lake. Again, it is likely that some of the deposits owe their existence largely to moving water in streams that had become laden with dust gathered from their tributaries and drainage basin, but there is little doubt that the winds were the principal distributing factor.